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RESEARCH REGARDING THE POSSIBILITY OF FERTILIZATION OF ARABLE LAND FROM LOCAL MANURE SOURCES USING GIS TECHNOLOGIES

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Abstract

Currently, in the Republic of Moldova about 94.4% of livestock is in small scale farms (small holdings), which makes it difficult to collect, store and use produced organic wastes. As a result, huge quantities of unused manure are thrown to the edge of roads, ridges, rivers, which leads to soil and water pollution. At the same time, soils involved in agricultural production are affected by various degradation processes, most of which are related to the lack of organic material and nutrients. The goal of the research was to reveal the possibility of manure use at local scale and to determine suitable sites for utilization of manure as organic fertilizer on example of Grinauti village, Riscani district in order. The selection was made by use of GIS technologies, namely through construction of GIS based decision model using Boolean logic. For decisional model construction were used eight decisional criteria relevant to study goal: soil bonitet; soil mobile phosphorus content; slope; proximity to access ways; proximity to springs and wells; proximity to localities and sheepfolds; proximity to aquatic objects; land use. In the result it was obtained a map of favorable places for use of manure. According to obtained decisional model 77.9% of arable areas are suitable for manure application.

Key words*: Boolean model, GIS, manure.*

INTRODUCTION

The problem of the use of manure in the Republic of Moldova is that about 94.4% of the livestock is in the smallholdings of the population, which makes it difficult to collect, store and use manure. According to the statistical data, about 400-500 thousand tons of manure per year are formed in the Republic of Moldova (Statistical yearbook, 2017), of which only 150-200 thousand tons were used annually.

As a result, big quantities of unused manure are thrown to the edges of roads, ravines, small rivers, leading to soil and surface or underground water pollution [Siuris, 2011 (1); Toma, 2008]. At the same time, manure is a complex fertilizer that contains all the elements necessary for plant growth and positively influences the physical condition and soil fertility [Siuris, 2011 (2); Toma, 2008].

Organic matter in manure is an important source for fertility and humus content recovery in soils, especially eroded ones [Siuris, 2011 (2); Toma, 2008]. It has a positive effect on the physical properties of soils, the ability to filter and retain water in soils, reducing water losses and attenuating drought (Toma, 2008). Manure fertilization also reduces water consumption by 25-35% to form the harvest unit (Andries, 2011). When manure decomposes, carbonic acid is formed. It contributes to the passage of nutrients from less soluble forms into easily soluble and accessible for plants forms. Some of the carbonic acid is eliminated in air and is assimilated by the plants. Soil fertilized with manure heats better, and temperature deviations are feet less [Siuris, 2011 (1)]. It has been established that manure produced in the Republic of Moldova is more qualitative, having a lower moisture content and a higher content of nutrients, compared to that obtained on podzolic soils or gray soils (Rusu and Plamadeala, 2011).

The purpose of the research was to highlight the possibility of using animal waste as an organic fertilizer to minimize environmental pollution under existing socio-economic conditions based on a concrete case study - Grinauti commune from Rascani district.

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MATERIALS AND METHODS

The research was carried out in the northern part of the Republic of Moldova, Rascani district, Grinauti commune.

To achieve the purpose of the research, a decision model was built on the basis of the Multicriteria Data Analysis (MDA) in the GIS environment. The MDA is meant to combine several factors or decision criteria according to a pre-established procedure (Malczewski, 1999). Specialized literature describes multiple and varied methods of constructing decision models of different complexity (Malczewski, 1999; Malczewski, 2006; Voogd, 1983). For this study was used one of the simplest models-combination based on Booleane algebra, a model known as the "logical Boolean model" which is performed by multiplying the criteria represented in the binary form (O'Sullivan and Unwin, 2010):

$$S_i = \prod_{j=1}^{n} Cr_i^j \qquad (1)$$

where:

S_i - represents the index of favorability for spatial unity *i*;

Cr_i^j - the value of criterion *j* for space unit *i*;

n - number of criteria.

Input criteria in the model are zero if the manure is not allowed for the given space unit and one when allowed. The same interpretation have the result of the Boolean decision model.

In order to build the decision model, the following factors relevant to the purpose were used: land use; proximity to localities and sheepfolds; proximity to access roads (asphalt road, country road); proximity to springs and wells; proximity to water areas (lakes, rivers, ravines); the soil quality represented by soil bonitet; slope; the amount of phosphorus in the soil. The input data in the decision model were generated taking into account the following considerations:

The content of mobile phosphorus in soils. There were no restrictions on the content of mobile phosphorus in soils because its content in the agricultural soil of the commune in most cases was below the optimal level of 3.0-4.5 mg/100 g of soil (Pedologic report…, 2005).

Slope degree. According to EU recommendations for Good Agricultural Practices, slopes of more than 15% represent a major risk of soil erosion. Thus, land with a slope of more than 15% was considered a restriction. The slopes were generated through the *ArcGIS Slope tool* based on the digital relief model. The digital relief model was generated through the *Topo to Raster tool* of ArcGIS based on the digitized curves and digits on the 1: 25000 topographic map available on the Land and Cadastre Agency of Moldova website.

Soil bonitet. On the basis of the soils pedological report and soil bonitet (Pedologic report…, 2005), it has been decided to consider areas favorable for manure application - areas where *soil bonitet* is higher than 50 points. Soils with *bonitet* of less than 50 points from studied area are severe and very severe eroded soils, hydromorphic or dynamomorphic soils, which are not recommended for application of fertilizers.

Proximity to access ways. For aesthetic reasons, it has been decided to use manure on land at a distance more than 25 m from roads (Basnet et al., 2001). Roads have been digitized from orthophoto images. *Buffer and Clip tools* have generated inadmissible areas for manure application.

Proximity to springs and wells. According to the recommendations developed by the Academy of Sciences of Moldova and the Ministry of Agriculture and Food Industry of the Republic of Moldova (Andrieș et al., 2005), it is not recommended to apply manure within the range of at least 50 m from the drinking water sources. The data on the spatial location of the springs and wells were collected with GPS in the field. Restrictions on the application of manure to the given criterion were generated in the same way as in the previous case.

Proximity to localities and sheepfolds. Based on the experience of other states, it was decided not to use manure within the 250 m radius (Basnet et al., 2001). An additional argument

for using a buffer zone for localities is that it will most likely reduce the impact of pollutants on aquifers near the locality. The localities and sheepfolds were extracted from the land use map. Inadmissible areas for manure application were generated as in the previous cases.

Proximity to aquatic objects. According to the Law on Strips and Areas for the Protection of Rivers and Lakes no. 440-XIII of April 27, 1995, art. 7 (Republic of Moldova), the width of riparian water protection strips is 100 m for large rivers and at least 20 m for small rivers (Low nr. 440 from 27.04.1995, Republic of Moldova). Thus, the land at a distance of less than 100 m from Raut and 25 m from the rest of the small rivers was considered inadmissible, and in the case of the lakes - 50 m. On the territory of the commune is located a wetland, so it was decided to impose here the same restrictions as in the case of small rivers.

Land use. Given the fact that fertilizers can be applied only on arable land, all other categories were considered inadmissible.

The decision criterion and the Boolean logic model were represented by raster spatial data with a resolution of 10 meters.

For the digitization of the initial spatial data (land use, phosphorus content, roads, rivers, lakes, curves and level elevations), the Quantum GIS open source GIS software was used. Geoprocessing and construction of the Boolean logic model was made in the licensed ArcGIS 9.0. The cartographic material was prepared on the basis of data available at the Institute of Pedology, Agrochemistry and Soil Protection „Nicolae Dimo" and the National Geospatial Data Fund administered by the Land and Cadastre Agency of Moldova.

Calculation of the amount of manure produced annually in the locality was performed using the parameters of manure accumulation in smallholdings published by Rusu (Rusu et al., 2012). The author proposes generalized manure indexes based on analysis of bibliographic sources.

Quality of manure usually varies according to the age and health status of animals and the nature of the fodder. In our research we used the average values of manure composition with natural moisture prepared for application (fermented). These values were obtained as a result of generalizing the multiannual data accumulated by the Organic Fertilizer Laboratory and Soil Fertility of IPASP „Nicolae Dimo" and published by Rusu and Plămădeală (Recommendations…, 1994; Rusu et al., 2012).

RESULTS AND DISCUSSIONS

Study of the present situation regarding manure generation in the Grinauti commune, Rascani district

At the time of the research on the territory of Grinauti commune there were no functional livestock complexes for animal breeding. All the animals were maintained in small scale farms (smallholdings). No individual or communal platforms for the collection of manure were found on the territory of the commune. So, in our research, only manure from smallholdings and poultry manure were studied. The amount of manure produced in a locality depends on the species, breed, age of the animals, their number and the length of the stabling period. The data on livestock and poultry in Grinauti commune were provided by the commune's town hall (Table 1). The annual amount of manure produced in the commune was calculated according to the Rusu method (Rusu et al., 2012) using average valuesfor each species, obtaining the following results:

Table 1. The amount of manure accumulated annually in the village of Grinauti, Rascani district

Species	Number of animals	The amount of manure accumulated in one year		
		from 1 animal	from all animals	share of total volume, %
Cattle	252	7.9	1991	56.9
Sheep and goats	702	0.5	351	10.0
Swine	320	1.8	576	16.5
Horse	36	5.1	184	5.2
Birds	8000	0.05	400	11.4
Total			**3501**	100

Site selection

The selection of sites for manure requires consideration of all the environmental factors indispensable for the use of this fertilizer. So, it is necessary to have land use data, soil condition, relief, hydrographic network of studied territory, existing road network and residential areas.

Figures 1-8 shows the input factors for the Boolean logic model represented in the binary form.

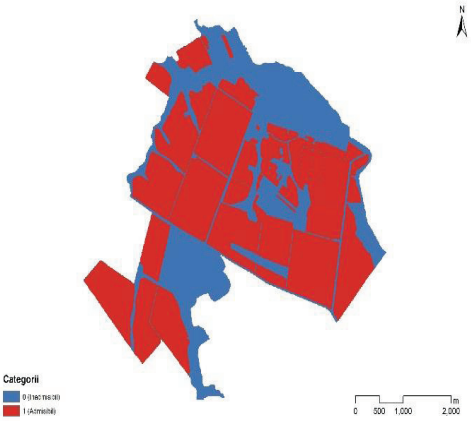

Figure 1. Entry factor Soil bonitet

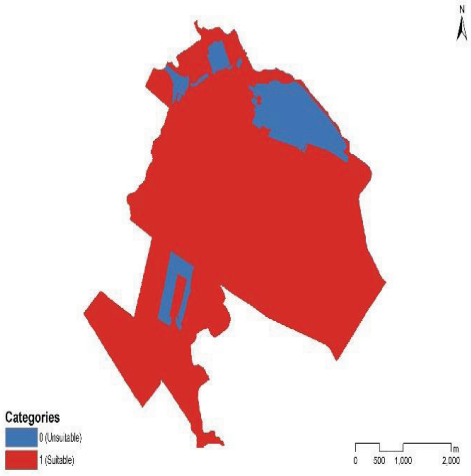

Figure 2. Entry factor Mobile phosphorus

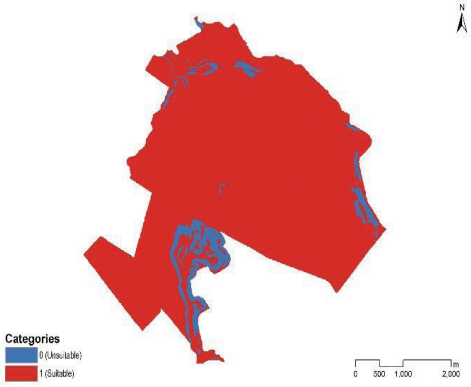

Figure 3. Entry factor Slope

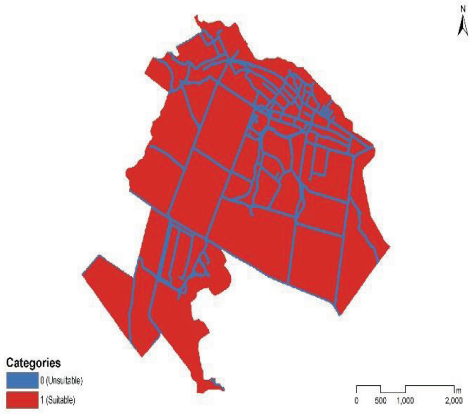

Figure 4. Entry factor Proximity from access ways

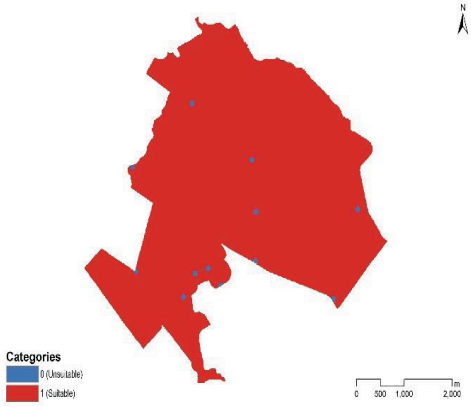

Figure 5. Entry factor Proximity from springs and wells

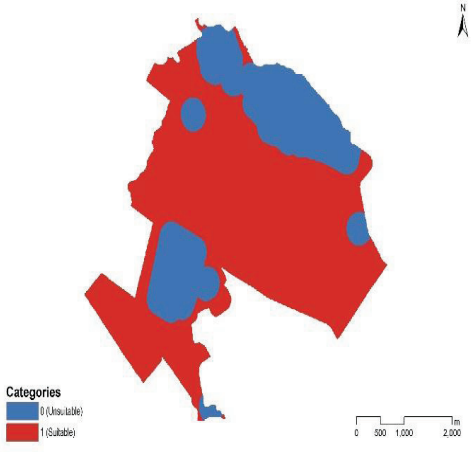

Figure 6. Entry factor Proximity to localities and sheepfolds

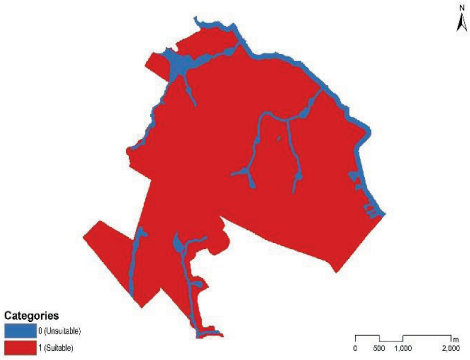

Figure 7. Entry factor Proximity from aquatic objects

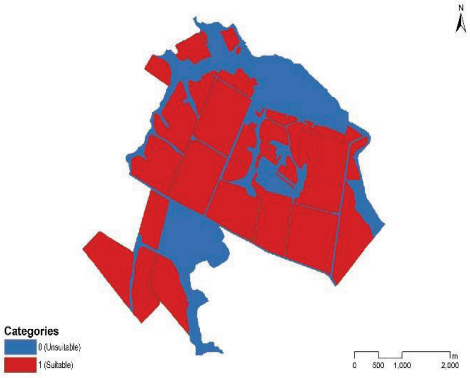

Figure 8. Entry factor Land use

The Boolean decision model was generated using the *Raster Calculator tool* based on the formula and input factors shown above. Applying the described methodology resulted in the decision model shown in Figure 9.

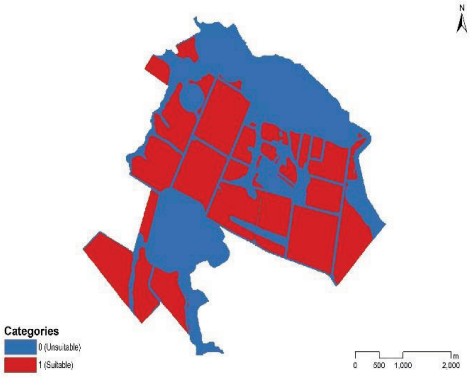

Figure 9. The decision model based on Boolean logic

According to the Boolean decision model, approximately 77.9% of the area of arable land is suitable for the application of manure as an organic fertilizer (Table 2).

Table 2. Suitable areas for the application of manure reported at arable land area

	m^2	ha	%
Arable lands	12856371	1285.64	100
Suitable area	10013200	1001.32	77.89

Calculation of organic fertilizer doses

Application of organic fertilizers in soils requires optimal doses calculated basing on the needs of plants and maximum admissible quantities that prevent environmental pollution. European Union legislation regulates the maximum allowable nitrogen intake because it can be easily leached from the soil (Council regulation…, 1991). Exceeding these doses may result in pollution of groundwater and surface water. According to this Directive, established in 1991, the annual nitrogen limit is 170 kg N/ha.

Maximum dose of fertilizer in this case is calculated according to the following formula:

$$D_{max} = 17 : N \qquad (2)$$

where:

D_{max} - dose of manure with the natural moisture content, t/ha;

N - total nitrogen content in fertilizer, % from mass with natural moisture content;

17 - coefficient that consider the maximum allowable nitrogen dose - 170 kg N/ha and recalculation of the fertilizer from kilograms in tonnes (Rusu et al., 2012).

According to our calculations, in a smallholding from Grinauti commune is produced mixed manure with a weighted average nitrogen content of 0.74%.

By replacing this data in formula 2 we obtain the maximum dose that can be applied in a round in the field:

$$D_{max} = 17 : 0{,}74 = \mathbf{23\ t/ha}$$

According to the literature, it is recommended to apply manure once every 4-5 years on the same land. In the case of soils with low humus

content (<2%) or eroded - once in 3-4 years (Andries, 2011; Recommendations…, 1994). With the total amount of manure produced annually in the commune (3501 t) and applying this fertilizer every five years (for example in a five-field crop rotation), we can fertilize 761 ha of agricultural land by applying the maximum allowable dose.

The maximum allowable dose determines the amount of nitrogen that can be applied over a 12-month period on a soil. In practice, however, we do not need to apply maximum doses, but only those necessary for crop plants - optimal manure doses.

Optimal dose of manure introduced for high and qualitative crops is calculated depending on the nitrogen content in fertilizer and the needs of the crops by the following formula:

$$D_{opt} = P \div (10N) \qquad (3)$$

where:

D_{opt} - the optimum dose of manure required for the expected harvest, t/ha;

P - the amount of nitrogen planned for incorporation, kg/ha;

N - total nitrogen content in fertilizer, %;

10 - the coefficient of recalculation of the fertilizer from kg/ha in t/ha.

According to the data on the average consumption of nutrients, for the production of 1 tonne of production are necessary: winter wheat - 33 kg of nitrogen, corn - 23 kg N, sugar beet - 40 kg N, sunflower - 40 kg N, tomatoes - 3 kg N, cabbage - 4 kg N, potato - 7.5 kg N, onion - 4 kg N (Recommendations, 2001; Recommendations, 2012; Rusu, 2005).

The amount of nitrogen required per hectare is calculated by multiplying the expected yield to nitrogen consumption per 1 tonne of production (Table 3). Optimal manure for the expected yields were calculated according to formula 3.

Thus, in order to obtain the expected crops for corn, sugar beet and sunflower fertilizer doses between 15.5-16.2 t/ha are required. If the nitrogen dose necessary for a crop is higher than the annual limit (in our case 23 t/ha), for example cabbage and potatos (Table 3), the maximum allowable dose will be applied to prevent nitrate pollution.

Table 3. Nitrogen requirements of crops and manure doses

Crop	Nitrogen content in manure, %	Nitrogen consumption per tonne of production, kg	Expected harvest, t/ha	The amount of nitrogen required per hectare, kg	Dose of manure, t/ha
Winter wheat	0.74	33.0	4	132	17.8
Corn	0.74	23.0	5	115	15.5
Sugar beet	0.74	40	30	120	16.2
Sunflower	0.74	40.0	3	120	16.2
Tomatoes	0.74	3.0	50	150	20.3
Cabbage	0.74	4.0	50	200	27.0
Potatoes	0.74	7.5	40	300	40.5
Onion	0.74	4.0	30	120	16.2

CONCLUSIONS

As a result of the research, a decision model based on the Boolean logic in the GIS environment was generated in order to determine suitable areas for the application of manure as organic fertilizer on the lands of Grinauti commune, Rascani district. The decision model was executed on the basis of eight decision criteria relevant to the purpose of the research. Basing on the decision model, it was established that manure can be used on a total area of 1001.32 ha, which represents 77.89% of the arable land area.

The maximum dose of manure with total nitrogen content of 0.74% that can be applied on studied territory is 23 t/ha.

The manure produced every year in the commune and applied once in five years in dose of 16 t/ha is sufficient for the fertilization of 1090 ha, so it is real to fertilize all the suitable area of the agricultural land in the commune.

ACKNOWLEDGEMENTS

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